Meteorological conditions for the triggering of landslides in Asturias (NW Spain)

A preliminary analysis of synoptic patterns

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INTRODUCTION

Principality of Asturias is one of the most landslide prone areas in the NW of Spain. Most of landslides take place during intense rainfall events, which point out precipitation as the main triggering factor (Domínguez-Cuesta et al., 1999). Regional climate is characterized by average annual precipitation and temperature of 960 mm and 13.3°C. According to the Köppen-Geiger classification (Peel et al., 2007), the majority of the area presents an Oceanic Temperate climate (Cfb).

Location of the study area.

Although there is no marked dry season, 2 different periods can be distinguished: (i) a wet period between October and May, characterized by the succession of frontal systems, and (ii) a period with lower precipitation (hereinafter named as dry period) between June and September, when heavy short storm episodes are usual.

BAPA landslide database

BAPA (Base de datos de *Argayos* del Principado de Asturias) is a regional landslide database developed for the study area. Data come from the revision of regional newspapers and reports from citizens and institutions. Landslides are classified in 3 categories considering the accuracy of its spatio-temporal location. Although the BAPA dataset covers the period 1980-2016, the inventory is reasonably complete from 2008 to present, gathering more than 1500 landslide records for this period. More information is available on the website:

B.A.P.A.

www.geol.uniovi.es/BAPA/

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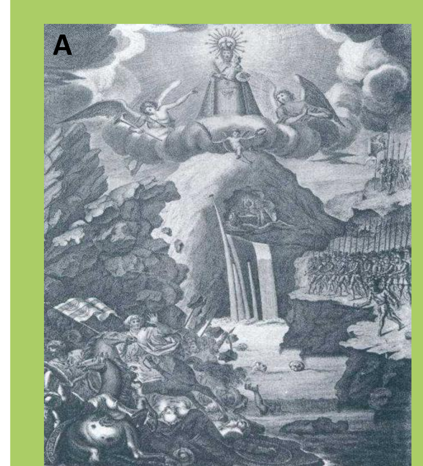
Main goal

To stablish a conceptual model of the most frequent synoptic meteorological patterns which generate rainfall-triggered landslide events in Asturias during the humid and dry periods.



But… what argayo means?

The word "argayo" comes from the Asturiano, a dialect traditionally used in the NW of the Iberian Peninsula. Its meaning is equivalent to landslide in a generic way. These phenomena are so frequent in the area that appear in ancient legends. In the VII century, King Pelayo won a battle in the Picos de Europa Mountains against the Muslim army. During the fighting, the Virgin helped the Christians triggering a huge rockfall over the enemies (on the left). How true is the old legend? In June 2013, a big landslide affected the small village of Sebrango, within the same mountains (on the right).

A. Battle of Covadonga, painted by J. Navia and J. Rodríguez (1790).
B. Landslide in Sebrango (N of Spain), *El Diario Montañés*.

METHODOLOGY

1. Selection of a study interval within the BAPA database with (i) a high level of completeness of the records, and (ii) availability of accurate spatio-temporal information.

2. Climatic characterization of the interval, considering: (i) the presence of wet-dry years, and (ii) the correlation between average monthly precipitation and total number of landslides per month. Precipitation data comes from six weather stations representative of the study area, managed by the AEMET (Agencia Estatal de Meteorological- Spanish Meteorological Agency).

3. Selection of particular episodes for study, characterized by (i) significant precipitation records (more than 30 mm during the dry period and 200 mm during the wet period), and (ii) a high number of landslide records (more than 2 during the dry period and more than 30 during the wet period).

4. Description of the selected episodes, considering: (i) number of recorded landslides, (ii) occurrence within the wet or dry period, (iii) total number of days, (iv) number of rainy days, (v) daily precipitation considering rainy days, and (vi) accumulated precipitation.

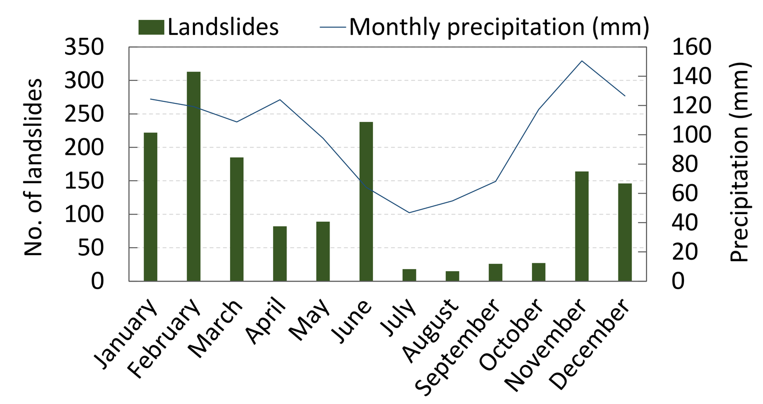
5. Definition of the meteorological synoptic conditions; to perform a detailed analysis, the episodes were divided into shorter events, only considering rainfall periods and dismissing those days without precipitation. Average meteorological patterns were calculated using data from the National Oceanic and Atmospheric Administration of the EEUU (NCAR/NCEP Reanalysis 1) through the free software Grid Analysis and Display System (GrADS). 7 parameters were used:
   - 500 hPa Temperature (°C)
   - 850 hPa Temperature (°C)
   - Sea level pressure (hPa)
   - 300 hPa Geopotential height (m)
   - 500 hPa Geopotential height (m)
   - 925 hPa Specific humidity (kg H_2Ov kg air^{-1})
   - 925 hPa Wind direction

6. Establishment of a conceptual model based on the main average meteorological patterns which are associated with relevant landslide events.

RESULTS

Studied interval

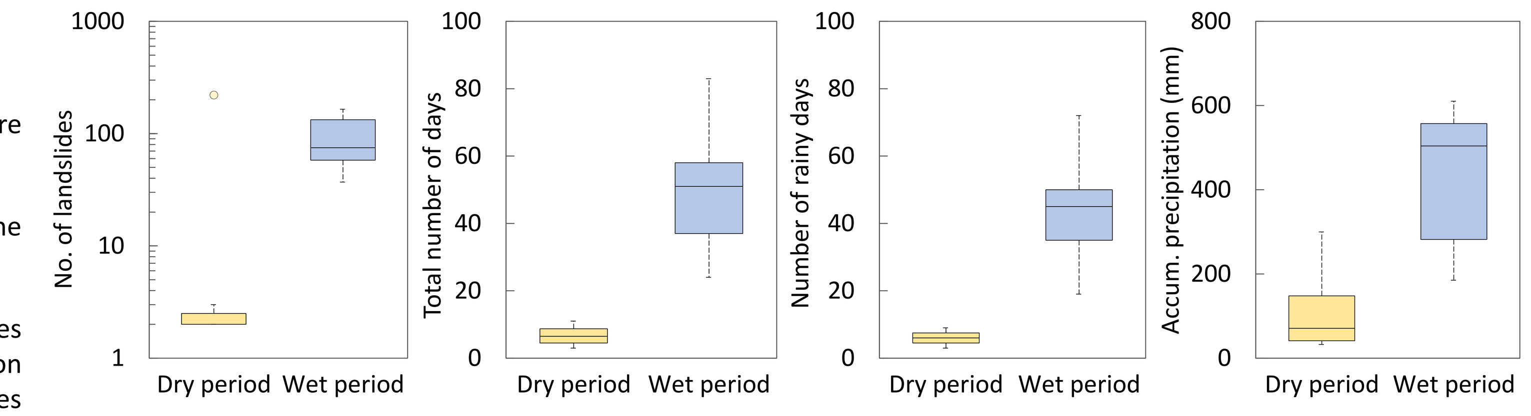
- PERIOD: 8 hydrological years → Oct. 2008-Sep. 2016
- RECORDS: 1525 landslides.
- DISTRIBUTION: the distribution of the landslides is linked to seasonal precipitation patterns; 81% of the landslides occurred during the wet period October-May, while 19% took place during the dry period June-September.



- CLIMATE: the interval is part of a wet sequence of years, with average annual precipitation values of 1276 mm; the hydrological years 2012/13 was classified as wet (1544 mm); the year 2011/12 was classified as dry (979 mm).

Selected episodes

- 13 episodes with a relevant number of landslides were defined.
- 70% of the landslides recorded during the studied interval are included within these defined episodes.
- 9 episodes correspond to the wet period and 4 episodes to the dry period.
- The wet period is characterized by long-lasting rainfall episodes with frequent rainfall gaps and high accumulated precipitation values, while the dry period shows short-lasting rainfall episodes with lower and more concentrated accumulated precipitation.

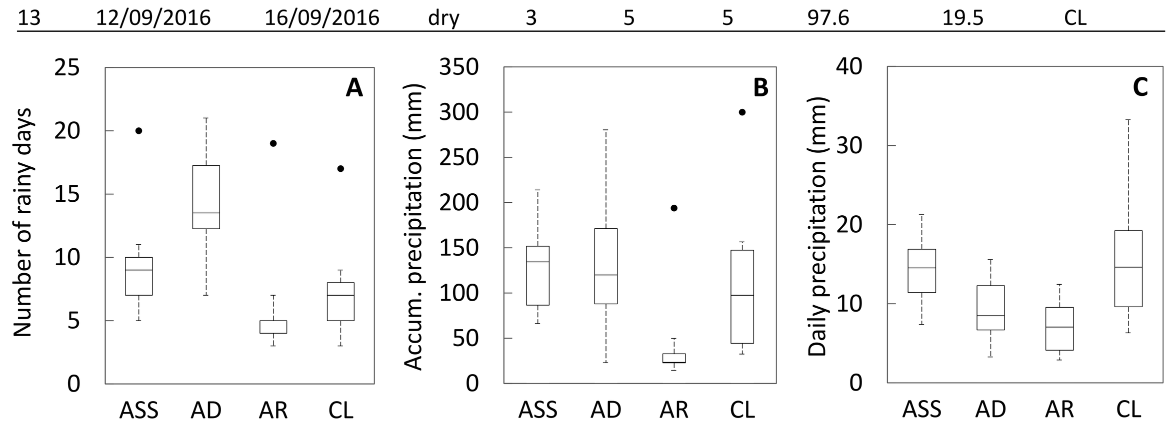


Characteristics of the selected episodes during the wet and dry periods

Definition of synoptic patterns within each episode

Summary statistics of the 32 events defined for the meteorological analysis.

ID	Initial	Final	Period	No. Lands.	Total days	Rainy days	Accum. P (mm)	Daily P (mm)	Pattern
1.1	27/10/2008	06/11/2008	wet	12	11	11	213.9	19.4	SAA
1.2	10/11/2008	13/11/2008	wet	2	4	3	22.7	7.6	AR
1.3	20/11/2008	26/11/2008	wet	67	7	7	111.3	15.9	SAA
1.4	28/11/2008	06/12/2008	wet	9	9	9	84.9	9.4	SAA
1.5	08/12/2008	18/12/2008	wet	55	11	10	150.2	15.0	SAA
2	08/06/2010	18/06/2010	dry	220	11	9	299.9	33.3	CL
3.1	15/01/2012	21/01/2012	wet	2	7	7	23.3	3.3	AR
3.2	25/01/2012	29/01/2012	wet	0	5	5	14.4	2.9	AR
3.3	31/01/2012	09/02/2012	wet	33	10	8	147.4	18.4	CL
4.1	10/01/2013	28/01/2013	wet	70	19	18	280.3	15.6	AD
4.2	31/01/2013	03/02/2013	wet	7	4	4	49.8	12.5	AR
4.3	05/02/2013	13/02/2013	wet	62	9	9	152.2	16.9	SAA
4.4	20/02/2013	28/02/2013	wet	13	9	9	66.3	7.4	SAA
5.1	07/03/2013	19/03/2013	wet	19	13	12	107.2	8.9	AD
5.2	23/03/2013	12/04/2013	wet	38	21	21	173.0	8.2	AD
6.1	26/04/2013	09/05/2013	wet	42	14	11	133.8	12.2	SAA
6.2	14/05/2013	19/05/2013	wet	6	6	6	67.0	11.2	SAA
7	16/06/2013	23/06/2013	dry	2	8	7	44.3	6.3	CL
8.1	13/12/2013	28/12/2013	wet	5	16	13	81.6	6.3	AD
8.2	01/01/2014	08/01/2014	wet	4	8	7	22.9	3.3	AD
8.3	13/01/2014	01/02/2014	wet	22	20	20	192.4	9.6	SAA
8.4	04/02/2014	20/02/2014	wet	14	17	14	78.5	5.6	AD
8.5	25/02/2014	05/03/2014	wet	24	9	9	120.7	13.4	AD
9	21/09/2014	23/09/2014	dry	2	3	3	32.5	10.8	CL
10.1	03/11/2014	17/11/2014	wet	7	15	15	119.2	7.9	AD
10.2	22/11/2014	09/12/2014	wet	20	18	17	156.6	9.2	CL
10.3	13/12/2014	17/12/2014	wet	23	5	5	70.1	14.0	SAA
11.1	15/01/2015	23/01/2015	wet	21	9	8	135.0	16.9	SAA
11.2	29/01/2015	07/02/2015	wet	48	10	10	212.6	21.3	SAA
11.3	13/02/2015	04/03/2015	wet	34	20	19	193.8	10.2	AR
12.1	01/01/2016	21/01/2016	wet	24	21	19	165.7	8.7	AD
12.2	06/02/2016	19/02/2016	wet	38	14	13	188.2	14.5	AD
12.3	24/02/2016	29/02/2016	wet	20	6	5	91.4	18.3	SAA
12.4	02/03/2016	11/03/2016	wet	38	10	10	137.7	13.8	SAA
13	12/09/2016	16/09/2016	dry	3	5	5	97.6	19.5	CL



*Comparison between the parameters: **A** Number of rainy days, **B** Accumulated precipitation and **C** Daily precipitation for the events included in each meteorological pattern.*

Cyclonic patterns SAA and AD include long-lasting events characterized by significant average accumulated precipitation values (118.6-129.9 mm) and low average daily precipitation values (9.2-14.4 mm). Furthermore, the events classified within the anticyclonic pattern AR are characterized by low average precipitation values (56.1 mm) accumulated in short-lasting periods, giving as a result a low average daily precipitation values (7.2 mm). In contrast, the events included in the CL pattern are characterized by high precipitation values (129.7 mm) accumulated in short periods, showing the highest average daily precipitation values (16.3 mm).

Average values considering the events included in each pattern.

Pattern	No. landslides	No. Days	No. Rainy days	Accum. P	Daily P
SAA	31.3	9.7	9.3	129.9	14.4
AD	24.3	15.3	14.1	111.0	9.2
AR	8.5	7.8	7.2	56.1	7.2
CL	46.7	9.2	8.2	129.7	16.3

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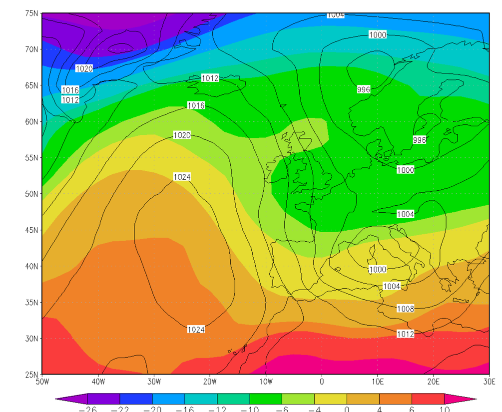
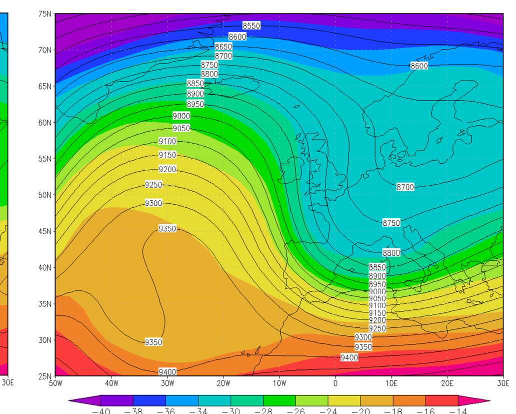
I. Strong Atlantic Anticyclone pattern (SAA)

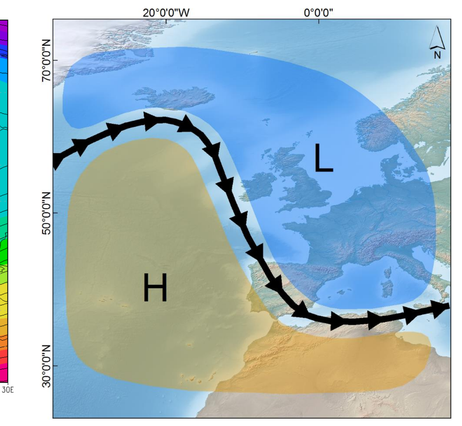
- Identified in 14 out of 36 events, is the most common pattern.
- Typical of the wet period.
- Presence of: (i) a strong Atlantic anticyclone, extended to the N of Azores in most of times; and (ii) a low pressure centre over the Mediterranean Sea or surrounding areas, leading to a norther humid and cold flow over Asturias.
- Frontal and post-frontal rainfall with high orographic forcing and medium precipitation due to the northern humid flow.
- Strong winds from the NW-N in all the troposphere, affecting the Iberian Peninsula.
- Characterized by polar or artic maritime air masses.



Event 29/01/2015 – 07/02/2015; SLP (hPa) and 850 hPa T (°C)



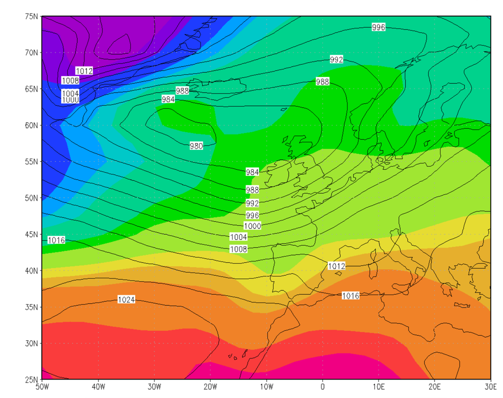
Event 29/01/2015 – 07/02/2015; 300 hPa GP and (m), 500 hPa T (°C)



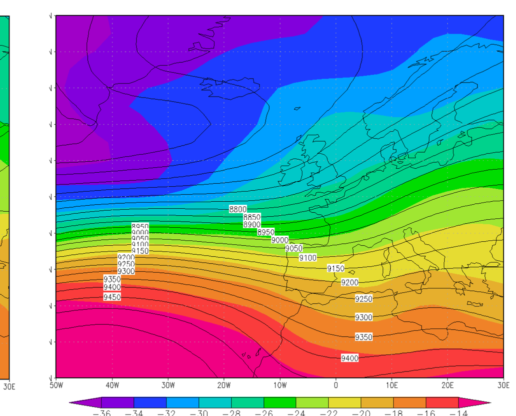
Idealized meteorological situation: SAA pattern

II. Atlantic Depression pattern (AD)

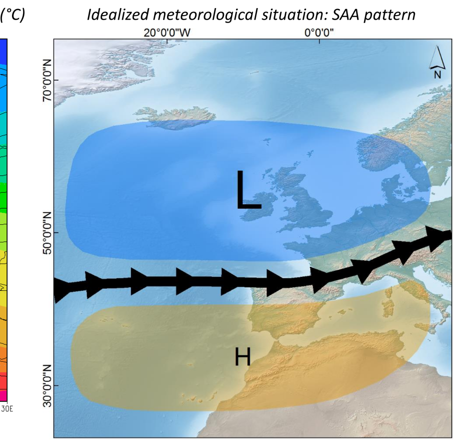
- Identified in 10 out of 36 events.
- Typical of the wet period.
- Presence of one or several a deep depressions near the Britannic Islands, moving from W to E according to the strong zonal flow and leading to a weak Azores Anticyclone displaced southwards.
- Frontal rainfall with medium orographic forcing and medium precipitation values.
- Very strong zonal winds in all the troposphere from the W-NW over the Iberian Peninsula.
- Characterized by polar maritime air masses.



Event 04/02/2014 – 20/02/2014, SLP (hPa) and 850 hPa T (°C)



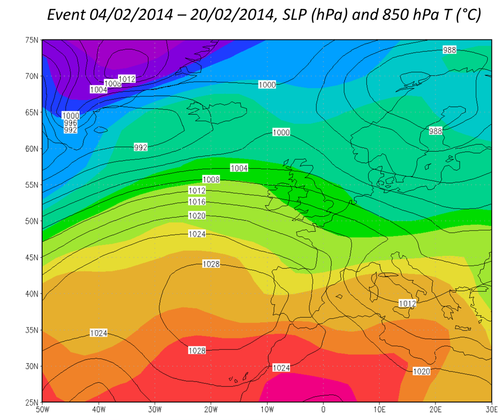
Event 04/02/2014 – 20/02/2014; 300 hPa GP and (m), 500 hPa T (°C)



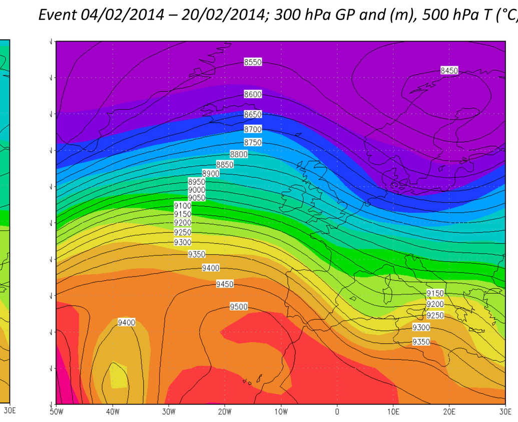
Idealized meteorological situation: AD pattern

III. Anticyclonic Ridge pattern (AR)

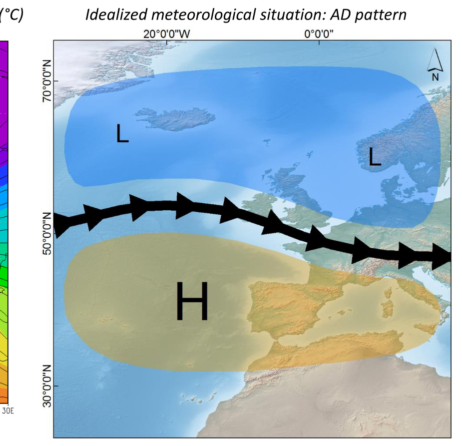
- Identified in 6 out of 36 events.
- Typical of the wet period.
- Presence of a strong Azores Anticyclone, extended as a ridge, affecting the N of the Iberian Peninsula.
- Low stratiform orographic precipitation values associated with the tail-end of weak fronts.
- Weak winds from the W-NW-N in all the troposphere, affecting the Iberian Peninsula, and more intense zonal winds located in mid-latitudes of Europe.
- Characterized by subtropical air masses.



Event 30/01/2013 – 03/02/2013, SLP (hPa) and 850 hPa T (°C)



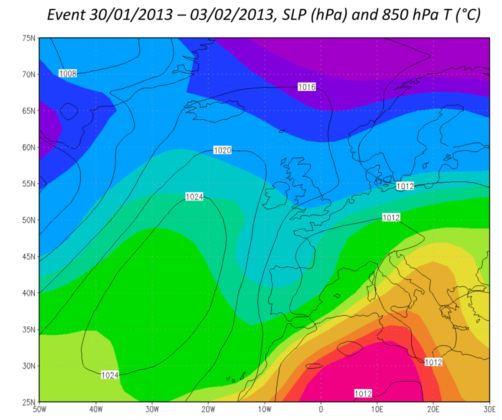
Event 30/01/2013 – 03/02/2013; 300 hPa GP and (m), 500 hPa T (°C)



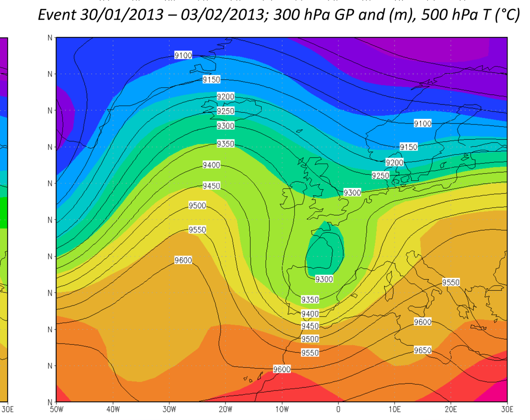
Idealized meteorological situation: AR pattern

IV. Cut-off Low pattern (CL)

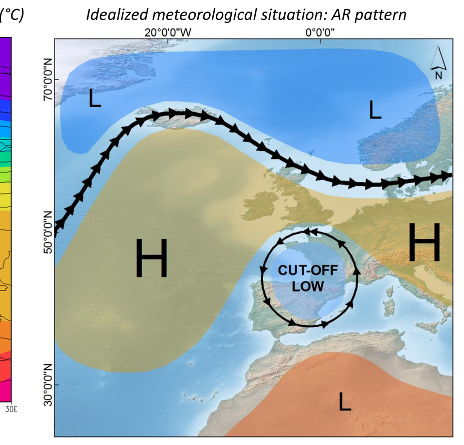
- Identified in 6 out of 36 events.
- The only pattern identified in the dry period, although it has also been identified in two episodes during the wet period.
- Presence of a Cut-off low extended down to the surface over or near the Iberian Peninsula.
- High convective precipitation values.
- Weak close-circulation winds in all the troposphere, with predominance of N-NW components.
- Characterized by subtropical air masses instabilized by cold air aloft and dynamic forcing.



Event 08/06/2010 – 18/06/2010, SLP (hPa) and 850 hPa T (°C)



Event 08/06/2010 – 18/06/2010; 300 hPa GP and (m), 500 hPa T (°C)



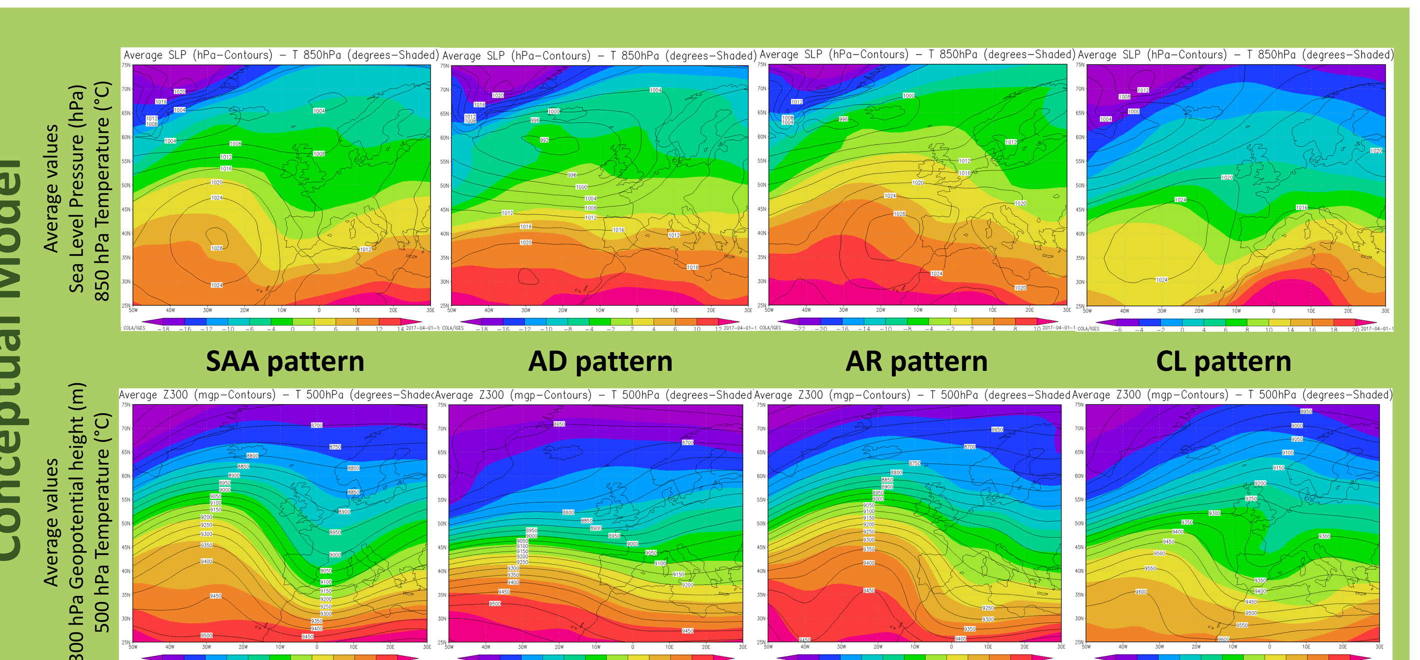
Idealized meteorological situation: CL pattern

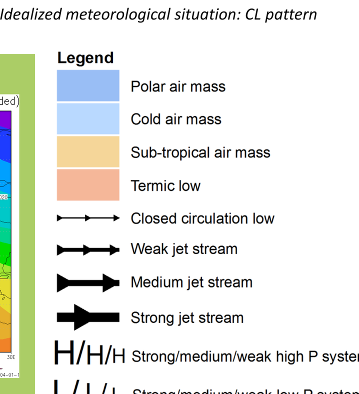
CONCLUSIONS

Between October and May (wet period), the cyclonic patterns SAA and AD generated the majority of the rainfalls episodes which triggered landslides, characterized by medium-intensity frontal precipitation with an orographic forcing. However, some anticyclonic and convective episodes were also observed. SAA and AD pattern are the most significant synoptic situations for the triggering of landslides in Asturias.

Between June and September, the Cut-off low is the only observed pattern, producing high-intensity convective precipitation during short periods. Although, in general, the number of landslides produced for these kind of episodes is reduced, the Cut-off low patterns may produce extraordinary and very unusual high-intensity precipitation events causing hundred of landslides, such as the case of June 2010 (220 landslides).

Conceptual Model





ACKNOWLEDGEMENTS

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